County of San Bernardino
Land Use Services Department
BUILDING AND SAFETY DIVISION

PERMIT GUIDELINES FOR RESIDENTIAL PV SYSTEMS

1. Basic site diagram identifying location of major components – not to scale.

   This is a simple diagram to show where the equipment is located. This can be a plot plan with the equipment clearly shown and identified on the plan. If PV array is ground-mounted, clearly show that system will be mounted within allowable zoned setbacks. See example EX-2 in appendix for reference.

2. Single-line electric diagram showing all major field-installed electrical components, wire identification and sizing, and grounding.

   This diagram needs to have sufficient detail to call out the electrical components, the wire types and sizes, number of conductors, and conduit type and size where needed. This will typically include detailed module information, series/parallel configuration of modules, details of the Photovoltaic Output Circuit, wire type and size of module wiring, type and size of any junction or combiner boxes, approximate length of conductors in PV array, approximate length of conductors from junction box to the photovoltaic power source disconnecting means. Other important information includes equipment grounding of the PV array and system grounding of the inverter. It will also include specific information on the PV inverter and all associated wire in and out of the inverter. The utility disconnect (if required by the utility) type and location should also be called out on the diagram and the means of connection to the building electrical system. See example EX-1 in appendix for reference.

3. Major component information

   A. Inverter information

      1) Model number and manufacturer's "cut sheets" for the specific model.

      2) Listing. Is the inverter listed by a Nationally Recognized Testing Laboratory (NRTL) to UL Std. 1741 and labeled "Utility-Interactive"? If the utility-interactive labeling is not provided, does the unit comply with the requirements of IEEE Std. 929-2000 as verified in the instruction manuals validated by the listing agency? For a current list of compliant inverters, visit the California Energy Commission's website, http://www.consumerenergycenter.org.cgi-bin/eligible_inverters.cgi. Some NRTL's have current listing information online as well.

      3) Maximum continuous output power at 40^0C.

      4) DC input voltage range.

      5) AC output voltage range.

   B. Module information

1) Manufacturer's "cut sheets" for the specific model.

2) Listing. The module should be listed to UL 1703. For a current list of modules that are listed to UL 1703, visit the California Energy Commission's website, http://www.consumerenergycenter.org/cgi-bin/eligible_pvmodules.cgi.

   Explanation: This module information is particularly important since it is used to calculate several current and voltage parameters required by the National Electrical Code (NEC). Listing information is necessary for NEC testing requirements [90.7, 100, 110.3]. (Numbers in brackets refer to sections in the 2002 NEC throughout this document.)

3) Open-circuit voltage (Voc)

   Explanation: Voc is needed to calculate maximum system voltage specified in NEC 690.7.

4) Maximum permissible system voltage

   Explanation: Maximum permissible system voltage (often 600 Vdc) is needed to show that the NEC 690.7 voltage does not exceed this value.

5) Short-circuit current (Isc)

   Explanation: Isc is needed to calculate short-circuit current specified in NEC 690.8.

6) Maximum series fuse rating

   Explanation: Maximum series fuse rating is needed to ensure that the proper overcurrent protection is provided for the modules and array wiring.

7) Maximum power (Pmax) at Standard Test Conditions (STC, 100W/m^2, 25^0C cell temp)

   Explanation: Maximum power at STC specifies the rated power of the PV module under simulated conditions.

8) Operating voltage (Vpmax)

   Explanation: Vpmax is needed to calculate system operating current. This is the current of the module when operating at Pmax and STC.

9) Operating current (Ipmax)

Explanation: Ipmax is needed to calculate system operating current. This is the current of the module when operating at Pmax and STC.

C. Battery information (if used)

10) Manufacturer's "cut sheets" for the specific model.

11) Nominal battery voltage for the system (Vbat)

Explanation: This is 2 Volts per cell for lead-acid batteries. A 24-cell lead-acid battery would have a nominal voltage of 48 volts.

4. Array Information

A. Number of modules in series, number of parallel source circuits, and total number of modules.

Explanation: Four items related to the PV array must be calculated and posted on a sign at the PV Power Source disconnect. The first item (1) characterizes the array design and provides the information necessary to calculate the four items needed to produce proper array identification for a sign required at the site.

From Example in Appendix One:

Number of modules in series = 10
Number of parallel source circuits = 2
Total number of modules = 10 x 2 = 20

B. Operating voltage (sum of series modules operating voltage in source circuit)

Explanation: Operating voltage is found by multiplying the module voltage at maximum power by the number of modules in a series string.

From the example in Appendix One:

Vpmax = 33 Volts
Number of modules in series = 10
33 Volts x 10 = 330 Volts

C. Operating current (sum of parallel source circuit operating currents)

Explanation: Operating current is found by multiplying the module current at maximum power for a module series string by the number of source circuits in parallel.

From the example in Appendix One:

Ipmax = 4.25 amps
Number of source circuits in parallel = 2
4.25 amps x 2 = 8.5 amps

D. Maximum system voltage [690.7]

Explanation: Maximum system voltage is calculated by multiplying the value of Voc on the listing label by the appropriate value on Table 690.7 in the NEC, and then multiplying that value by the number of modules in a series string. The table in the NEC is based on crystalline silicon modules and uses coldest expected temperature at a site to derive the correction factor. Some modules do not have the same temperature characteristics as crystalline silicon so the manufacturer's instructions must be consulted to determine the proper way to correct voltage based on coldest expected temperature. A conservative estimate for coldest expected temperature is the lowest recorded temperature at a location. An engineering evaluation may show that maximum voltage is less than this method suggests. If sufficient substantiation accompanies this evaluation, a lesser value for maximum system voltage should be allowed.

From the example in Appendix One:

Module Voc = 42.8 Volts
Number of Modules in Series = 10
Lowest temperature on record = 15^0F (coeff. Of 1.13 from 690.7)
Maximum System Voltage = 42.8 x 10 x 1.13 = 484 Volts < 600 Volts

E. Short-circuit current [690.8]

Explanation: Short-circuit current is calculated by multiplying the value of Isc on the listing label by the number of source circuits operating in parallel, then multiplying this value by 125% to account for extended periods of sunlight above the tested solar intensity (rated irradiance = 1000 W/m^2; maximum sustained irradiance = 1250 W/m^2).

From the example in Appendix One:

Isc = 4.7 amps
Number of source circuits in parallel = 2
4.7 amps x 2 x 1.25 = 11.7 amps

5. Wiring and Overcurrent Protection

A. Wire Type

PV module interconnections should be 900C wet-rated conductors. Allowable wire types are as follows:

- USE-2 single conductor cable for exposed applications
- Type TC multiconductor cable for exposed applications with THWN-2 or XHHW-2 or RHW-2 or equivalent 90^0C wet-rated conductors in the cable.
- Type THHW-2 or RHW-2 or equivalent 90^0C wet-rated conductors in high temperature conduit (conduit rated for a minimum of 75^0C wet conditions).

Explanation of need for high temperature wiring:

Typical temperature for PV modules in full sun at 20^0C outdoor temperature is 50^0C. This is a 30^0C rise above outdoor temperatures. On the hottest day of the year, outdoor temperatures can reach $40\text{-}45^0$C in many locations throughout the United States. This means that the PV module will be operating at 75^0C on the hottest day of the year (45^0C+30^0C=75^0C). 75^0C wire is insufficient for connection to a hot PV module under this condition and conduit rated for a minimum of 75^0C wet conditions is necessary to contain wires that must be in conduit.

To further support the concern over the high temperature of PV modules, a new fine print note has been added to the 2005 NEC.

690.31(A) FPN: Photovoltaic modules operate at elevated temperatures when exposed to high ambient temperatures and to bright sunlight. These temperatures may routinely exceed 70^0C (158^0F) in many locations. Module interconnection conductors are available with insulation rated for wet locations and a temperature rating of 90^0C (194^0F) or greater.

B. Conductor Ampacity:

Correct maximum current and ampacity calculations should be provided for each circuit. (Ampacity of conductors must be sufficient for application.)

1) The maximum PV source circuit current is the sum of parallel module rated short circuit currents multiplied by 125 percent [690.8(A)(1)].

   Explanation: The 125 percent increase over the rated short circuit current is to account for sustained periods when the sun's intensity (irradiance) can be 25% greater than the rated irradiance. (Rated irradiance = 1000 W/m^2; maximum sustained irradiance = 1250 W/m^2).

   <u>From the example in Appendix One</u>:

   Isc = 4.7 amps
   4.7 amps x 1.25 = 5.9 amps

2) The maximum source circuit conductor ampacity is 125 percent of the maximum PV source circuit current [690.8(B)(1)].

Explanation: The 125 percent increase over the maximum PV Source Circuit current is to account for the standard listing of wire to 80% of maximum circuit current for continuous duty.

Example from Appendix One:

Minimum ampacity calculation
Isc = 4.7 amps
Maximum PV source Circuit Current = 4.7 amps x 1.25 = 5.9 amps
Minimum Source Circuit Conductor Ampacity = 5.9 amps x 1.25 = 7.3 amps

3) Minimum photovoltaic output circuit conductor ampacity is the sum of the maximum current of the parallel source circuits [690.8(B)(1)] times 1.25.

Explanation: Paralleled currents add together. The 125 percent increase over the PV output circuit current is to account for the standard listing of wire to 80% of maximum circuit current for continuous duty.

From the example in Appendix One:

Minimum Source Circuit Conductor Ampacity = 7.3 amps
Number of source circuits in parallel = 2
7.3 amps x 2 = 14.6 amps

Calculating ampacity of conductors used for the PV output circuit can be an involved process. If more than three current carrying conductors are installed in the conduit, Table 310.15(B)(2)(a) is used to adjust the conductor ampacity. If more than 10% of the circuit, or 10 feet of the circuit is in conduit in direct sunlight, Article 310.10 has a new fine print note in the 2005 NEC.

310.10 FPN No. 2: Conductors installed in conduit exposed to direct sunlight in close proximity to rooftops have been shown, under certain conditions, to experience a temperature rise of 17^0C (30^0F) above ambient temperature on which the ampacity is based.

This note instructs the installer to increase the apparent ambient temperature correction factor used in Table 310.16. For instance, should the maximum ambient temperature be 45^0C (113^0F), for rooftop sunlit conduit, the new ambient temperature is evaluated at 62^0C (144^0F). This has a dramatic impact on the allowable ampacity of a conductor.

4) Minimum inverter output circuit conductor ampacity must be equal or greater than the inverter continuous output current rating times 1.25.

Explanation: The inverter output circuit current is calculated from the maximum continuous power rating at nominal AC voltage. The 125 percent increase over the maximum Inverter Output Circuit current is to account for the standard listing of wire to 80% of maximum circuit current for continuous duty.

From the example in Appendix One:
Inverter continuous output rating = 2500 Watts
Minimum inverter voltage = 211 Volts
Maximum operating current = 2500 Watts/211 Volts = 12 Amps
Min. Inverter Output Circuit Ampacity = 12 Amps x 1.25 = 15 Amps

C. Overcurrent protection: Necessary fuses or circuit breakers must be properly sized and specified for each circuit.

1) Source circuit overcurrent protection must be sized so that both the PV module and the conductor from the module to the overcurrent device are properly protected [690.9(A), 240.20(A)]. PV modules must be protected so that the maximum series fuse rating, printed on the listing label, is not exceeded. It is important to note that even though the listing label states "fuse" rating, a more accurate term would be the "maximum series overcurrent protection" rating since either a fuse or a circuit breaker may be used to satisfy this listing requirement. The module may be protected either by installing fuses or circuit breakers in a series string of modules or by the design of the PV system.

Inverters listed with a maximum utility back feed current that is well above 1 amp (typically equal to the maximum allowable output overcurrent protection) must be assumed to provide back feed current to the PV array. Each source circuit must have overcurrent protection that is greater than or equal to the minimum PV Source Circuit current rating and less than or equal to the maximum series fuse rating.

Explanation: For an array with a minimum source circuit current rating of 7.3 amps and a maximum series fuse rating of 15 amps, the minimum fuse rating would be 8 amps (next larger fuse rating above 7.3 amps) and the maximum would be 15 amps.

For an inverter listed with a maximum utility back feed current that is zero, or well under 1 amp (e.g. Fronius IG 5100), two source circuits can be connected to the inverter without requiring overcurrent protection on either circuit.

Explanation: If an array is connected to a non-back feeding source containing two strings in parallel, the maximum current in a string is equal to the current from the other string in parallel. If the maximum current of each string is 5.9 Amps, then the maximum current at any PV module is 5.9 Amps and the maximum series fuse rating of the module will never be exceeded.

2) Battery (if used) overcurrent protection must have a sufficient voltage and ampere-interrupt rating (AIR) to withstand the operating conditions of the battery system. [NEC 690.9(D)]

   Explanation: Batteries can produce thousands of amps of current during a short circuit. The overcurrent protection must be able to operate properly at the highest voltage produced by the battery and while exposed to the full the short circuit current supplied by the battery.

3) Inverter output circuit overcurrent protection should be sized and protected according to the manufacturer's directions. The circuit and corresponding overcurrent protection should be sized at a 125% of the maximum continuous output of the inverter [NEC 215.3 Overcurrent for Feeder Circuits]. The inverter may also have a maximum allowable overcurrent requirement.

   Explanation: For instance, the SMA SWR2500U has a maximum continuous output of 12 amps and a maximum allowable overcurrent protection of 15 amps. This means that the minimum allowable overcurrent is 15 amps (12 amps x 1.25 = 15 amps) and a maximum of 15 amps.

4) NEC 690.64(B) covers the requirements for Point of Connection of the PV inverter to the building electrical system. The most common method of connection is through a dedicated circuit breaker to a panel busbar. The allowable size of the supply breaker depends on whether or not the facility is a dwelling. If the building is a dwelling, the sum of the supply breakers feeding the busbar of a panel can be up to 120% of the busbar rating. Non-dwelling facilities do not allow the sum of the supply breakers to exceed the busbar rating.

   Explanation: A dwelling with a service panel containing a 100-amp busbar and a 100-amp main breaker will allow breakers totaling 120% of the busbar rating (120-amps). Since the main breaker is 100 amps, the PV breaker can be up to 20 amps without exceeding the 120% allowance. For a service panel with a 125-amp busbar and a 100-amp main breaker, this provision will allow up to a 50 amp breaker (125 amps x 1.2 = 150 amps; 150 amps – 100 amp main breaker = 50 amp PV breaker).

5) A new provision in the 2005 NEC clarifies the fact that dedicated circuit breakers backfed from listed utility-interactive inverters do not need to be individually clamped to the panelboard busbars. This has always been the case, but many inspectors have employed the provisions of NEC 408.36(F) that the breaker be secured in place by additional fastener. Utility-interactive inverters do not require this fastener since they are designed to shut down immediately should the dedicated breaker become disconnected from the busbar under any condition.

NEC 690.64(B) covers the requirements for Point of Connection of the PV inverter to the building electrical system. The most common method of connection.

6) Provisions for the photovoltaic power source disconnecting means:

The 2005 NEC states in 690.14(C)(1), "Location. The photovoltaic disconnecting means shall be installed at a readily accessible location either outside of a building or structure or inside nearest the point of entrance of the system conductors. The photovoltaic system disconnecting means shall not be installed in bathrooms."

a) Readily accessible – Article 100 states, "Accessible, Readily (Readily Accessible). Capable of being reached quickly for operation, renewal, or inspections without requiring those to whom ready access is requisite to climb over or remove obstacles or to resort to portable ladders, and so forth.

b) Readily accessible provision is primarily for emergency operation. If the disconnect is not mounted in close proximity of the service entrance disconnect (usually within 10 feet of the meter location or service disconnect switch), then a diagram or directory must be provided to clearly identify where the disconnect is located.

c) A rooftop disconnect on a residential roof will normally not quality as a readily accessible disconnect.

A new exception to this requirement has been added to provide additional clarification for residential and building integrated PV systems. This exception reads:

"Exception: Installations that comply with 690.31(E) shall be permitted to have the disconnecting means located remote from the point of entry of the system conductors."

690.31(E) states:

"(E) Direct-Current Photovoltaic Source and Output Circuits Inside a Building. Where direct current photovoltaic source or output circuits of a utility-interactive inverter from a building-integrated or other photovoltaic system are run inside a building or structure, they shall be contained in metallic raceways or enclosures from the point of penetration of the surface of the building or structure to the first readily accessible disconnecting means. The disconnecting means shall comply with 690.14(A) through 690.14(D)."

7) Grounding

The NEC requires [690.41] that all systems operating above 50 volts have one conductor referenced to ground unless the system complies with the requirements of 690.35 for ungrounded PV arrays.

The fine print note in 690.42 states “FPN: Locating the grounding connection point as close as practicable to the photovoltaic source better protects the system from voltage surges due to lightning”. Although this may be an accurate statement, changing the grounding location necessitates that inverter be moved to the grounding location since many inverters require that the array be grounded in the inverter. There are many reasons why moving the inverter away from the service entrance is not good design and these reasons generally outweigh any lightning protection benefits received by grounding the system conductors near the array.

The code also requires that all exposed non-current-carrying metal parts of module frames, equipment, and conductor enclosures be grounded regardless of system voltage [690.43].

a) Equipment grounding conductor sizing [690.45].

The size of the equipment grounding conductor is dependent on whether the system has ground fault protection (GFP) equipment or not. The provisions for GFP equipment are stated in 690.5. Many residential inverters have GFP equipment integral to the inverter and require that the PV array be grounded at the inverter only.

i) Systems without ground fault protection equipment

The NEC requires that equipment grounding conductors for systems without GFP equipment be sized for 125% of circuit short circuit current [690.45] (calculated in 5)b)i) in this guide). The shortcut method of sizing this conductor is simply to size the equipment grounding conductor the same size as the current carrying conductors. Calculating 125% of circuit Isc may produce a conductor size that is one size smaller than the current carrying conductors, but that must be calculated for confirmation.

ii) Systems with ground fault protection equipment

Size equipment grounding conductor according to NEC Table 250.122.

b) System grounding conductor sizing

i) AC System

Size grounding electrode conductor according to NEC Table 250.66.

ii) DC System

Size grounding electrode conductor according to NEC 250.166. This results in a minimum size of 8 AWG.

8) Array Mounting Information

Provide information on weight of array (pounds per square foot). This includes the weight of the modules and all panelizing hardware (e.g. modules, rails and associated hardware).

a) If array is roof mounted:

Provide information on roof structure(s) construction (truss or rafter size and spacing) and roofing material.

i) Is the weight distribution of the system greater than 3.5 lbs. per square foot or more than 10 sq. ft. of tributary area supported at one point? If yes, engineering calculations may be required.

ii) Specify rafter or truss size and spacing – engineering calculations may be required if non-standard.

iii) Identify roofing type (e.g. comp shingle, masonry tile, shake, etc.).

iv) Provide engineering details of PV panel mounting attachments to the roof-framing members. Several well-engineered mounting systems are now available for installers to use. These designs often include detailed engineering specifications and details. Installers who use their own designs will need to provide their own details and engineering calculations with their design.

v) Identify method of sealing roof penetrations (e.g. flashing, sealed with urethane caulk, etc.).

b) If array is ground mounted:

i) Show array supports, framing members, and foundation posts and footings.

ii) Provide information on mounting structure(s) construction. If the mounting structure is unfamiliar to the local jurisdiction and is more than six feet (6') above grade, it may require engineering calculations.

iii) Show detail on module attachment method to mounting structure.